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MONITORING STATION FOR STUDYING POPULATIONS OF *RETICULITERMES* (ISOPTERA: RHINOTERMITIDAE) IN CALIFORNIA

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Abstract.—The first appearance of live termites or feeding damage in previously reported subterranean termite monitor designs occur within several months of installation and involves <15% of the total number of monitors. The ability of monitors to sustain subterranean termite foraging often is less than 50%. The design of the monitor used for this study, featuring above and below ground sections, sustained subterranean termite foraging for over 80% of monitors for both wildland and residential sites for at least 2 years. The monitor is robust and can accommodate seasonal fluctuation in termite foraging activity. The modifications of this monitor and possible underlying mechanisms for increased sustainability of termite foraging are compared to already described collecting devices utilizing wooden stakes, toilet paper, corrugated paper, and below-ground monitoring systems.

Key Words—Insecta, termite monitoring, ground-based station, Isoptera, Rhinotermitidae, *Reticulitermes,* subterranean termite, bait stations

Subterranean termites, are the most economically important of the 45 recognized termite species that occur in the United States (Su & Scheffrahn 1990). The damage and repair costs to structures attributed to subterranean termites are extensive and exceed the total damage caused by fires, earthquakes, tornadoes, and all other natural disasters combined (Hedges 1992). In California, pest species in the genus *Reticulitermes* Holmgren are the most important termite pest of structures (Weesner 1965, Ebeling 1975).

Subterranean termites gather cellulose, in the form of wood, by sending workers foraging into the surrounding environment. Because the nests are primarily below ground, lines of workers must forage out via galleries and shelter tubes made of soil to sources of wood. There are many chemical cues from the environment and pheromone cues from the queen and other caste members involved in foraging behavior (Wilson 1971). However, studies on the natural foraging behavior of subterranean termites is complicated by their small size, cryptic nature, and eusocial behavior (Forschler & Townsend 1996).

During the last twenty-five years, many studies have attempted to describe the population size, caste demographics, and foraging behavior for subterranean termites. The earliest foraging behavior studies were of species in the genera *Gnathamitermes* Light, *Heterotermes* Froggatt, and *Reticulitermes* Holmgren and used ground-based devices composed primarily of wood (stakes and blocks) or toilet paper rolls (Esenther & Gray 1968; La Fage et al. 1973; Tamashiro et al. 1973;

Beard 1974; Esenther & Beal 1974, 1978; Haverty et al. 1975, 1976; Esenther 1980; French & Robinson 1980, 1981; Thompson 1985; Su & Scheffrahn 1986; Jones et al. 1987). Other innovations in ground-based device design included using corrugated paper (Esenther 1980, La Fage et al. 1983, French & Robinson 1985, Grace 1989), below-ground conduit systems (French 1991a, b; Lenz & Creffield 1993), radioisotopes (Spragg & Paton 1980, Chen & Henderson 1994), hollow stakes (Ewart et al. 1992), and large-volume collection devices (Tamashiro et al. 1973, French & Robinson 1981, La Fage et al. 1983, Grace et al. 1995). Several of these ground-based monitoring devices are now commercially available for subterranean termite control using slow acting baits (Su et al. 1995a, Potter 1997, Benson et al. 1997). Habitat sampling and exhaustive trapping also have been tried as means for estimating subterranean termite numbers (Haverty & Nutting 1975, Uekert et al. 1976, French & Robinson 1981, La Fage et al. 1983, Jones et al. 1987, Howard et al. 1982).

The greatest proliferation of reports on subterranean termite population levels and foraging behavior is a result of the innovation of marking foraging termites to estimate their numbers using mark-recapture methods. The first markers used were the water soluble dye Fast Green (Fujii 1975) and the fat soluble dye Sudan Red 7B (Lai 1977, Lai et al 1983, Su et al. 1983) with *Coptotermes formosanus* Shiraki. Subsequent laboratory screening has identified several dozen potential dyes for marking species of *Coptotermes* Wasmann and *Reticulitermes* Holmgren (Grace & Abdallay 1989, 1990; Su et al. 1991; Oi & Su 1994). Fluorescent spray paint topically applied to foragers has also been used as a marker for determining foraging territories (Forschler 1994). Many studies have reported on colony size and foraging area using marked subterranean termite foragers; the objective for many of these studies has been the evaluation of commercial baits for control (Su & Scheffrahn 1988; Grace et al. 1989; Grace 1990; Jones 1990; Grace 1992; Su et al. 1993; Su 1994; Haagsma & Rust 1995; Su et al. 1995a,b; Forschler 1996; Forschler & Ryder 1996; Forschler & Townsend 1996; Grace et al. 1996; Pawson & Gold 1996; Sornnuwat et al. 1996; Benson et al. 1997).

There is considerable variance in reporting of subterranean termite population size and foraging territory. Much of the variance can be attributed to climatic conditions (Haagsma & Rust 1995, Forschler & Townsend 1996, Sornnuwat et al. 1996), habitat (Su et al. 1993, Haagsma & Rust 1995, Sornnuwat et al. 1996), geographic differences (Forschler & Townsend 1996), differences in monitoring technique (Forschler & Townsend 1996), and violation of assumptions when using mark-recapture methods (Thorne et al. 1996, Forschler & Townsend 1996). The diversity of subterranean termite species vary in California (Haverty & Nelson 1997) and other regions in the United States (Weesner 1970, Forschler & Townsend 1996) and also may contribute to variances reported in population estimates and foraging territories.

The ability of monitoring devices to sustain subterranean termite numbers and activity is another source of variance to consider during foraging behavior studies and bait efficacy trials. There are few published studies that report the number of live subterranean termites or percentage of monitors containing live termites for ground-based devices, especially at monthly or more frequent intervals (Haagsma & Rust 1995, Forschler 1996). Paramount to understanding the natural foraging behavior or control attempts for subterranean termites is the ability of monitoring stations to sustain subterranean termites long enough for mark-recapture estimates or baiting trials to take place. In this paper, we describe the results of a almost three-year study involving monthly visits to over 100 ground-base monitoring devices at two locations in Northern California. The ability of our monitor to contain and sustain live subterranean termites and feeding damage and comparisons with already reported monitor designs will be discussed.

Materials and Methods

Field Sites.—We utilized one wildland and one residential location. The wildland site was used to study *Reticulitermes* colonies in a "natural" setting without the interference of man-made structures. The residential site was used to develop an understanding of the ecology and behavior of *Reticulitermes* under urban conditions. Wildland studies were conducted in the Eddy Arboretum in the western portion of the Pacific Southwest Research Station's Institute of Forest Genetics (IFG) near Placerville County, California. IFG is located between Placerville and Camino at an elevation of about 775m. Our site was approximately 4 hectares with a 50-year old plantation of mixed *Pinus* species. Trees were spaced at 4-m intervals and the canopy is partially closed.

The residential location used was in Novato, Marin County north of San Francisco. The site consisted of a single family dwelling (that serves as a church rectory), a small church, and extensive gardens, walks, and large trees on a one hectare lot. The rectory is heavily infested with *Reticulitermes.* No remedial control with soil termiticides was initiated to terminate the attack on the structures during the course of the study.

Site Preparations and Monitoring Stations.—Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) sapwood stakes were driven into the soil in a 2 × 2-m grid at IFG (January 1993) or at 1-m intervals around structures at the residential site (March 1994) and checked four times from July 1993 to April 1996 for IFG for signs of termite activity (e.g., live termites and feeding damage). For the St. Francis Church site, stakes were checked twice from July 1994 to May 1995 for signs of termite activity. The number of termites observed at stakes for each inspection check was estimated using the following scale: 0 = no termites; 1 = 1 to 20; 2 = 21 to 50; 3 = 51 to 100; 4 = 101 to 300; and 5 = over 300. Damage to stakes was also estimated and scaled: 0 = no damage; 1 = minor etching; 2 = $<$10%; 3 = 11 to 24%; 4 = 25 to 50%; 5 $>$ 50%. Stakes with live termites and a damage rating of at least 4 (25 to 50%) at the time of inspection had a monitoring station installed. Stakes were not removed when a monitor was installed.

The monitoring station design and installation is a modification of that used by Grace (1989), French (1991a), and Su and Scheffrahn (1986) and resembles the approach taken by Grace et al. (1995). The initial installation of monitoring stations included coring a 15-cm diameter hole into the soil to a depth of ca. 40 cm, about 10 to 20 cm from stakes with live subterranean termites and feeding damage. Before placement of the monitoring station, the hole was filled with about 10 to 20 liters of water to thoroughly wet the soil touching the monitoring station. Monitoring stations consisted of two 30-cm sections of 10-cm diameter ABS pipe adjoined with an ABS coupling, buried into the soil to a depth of about 30 cm with about 30 cm of the monitoring station above the soil, capped with a screw-in lid, with a wood bundle placed inside (Fig. 1). In about 20% of the monitoring stations, the interior of the below-ground portion was filled with a 30-cm long roll of corrugated paper as well as lined with one thickness of corrugated paper (Fig. 1). The inner volume of the in-ground portion was filled with soil to approximately the same level as outside the monitoring station.

The aggregation and feeding substrate used during the study was a bundle of 11 to 13 pieces of 30 × 3 × 1-cm, aged ponderosa pine cut on both ends and held together with rubber bands (Fig. 1). Wooden slats were aged by placement on the roof of one of the author's home in Lafayette, CA, and exposed to ambient weather conditions for one year prior to usage. The wood bundles were thoroughly soaked in water 24 hours before being placed into the monitoring station. Bundles were inserted into the monitoring station with the cut end of all pieces of wood in contact with the soil. The monitoring station was then sealed with the screw-in cap. Sixty-five monitoring stations were initially installed at IFG (summer 1993) (Fig. 2). Thirty-nine stations were installed at the Novato site in spring 1994 and 1996 (Fig. 3).

Station Visitation Rates and Data Recorded.—Once installed, each monitoring station was visited monthly, the wood bundle was removed, and replaced with another soaked bundle. Presence or absence of termites or termite activity (e.g., feeding damage and shelter tubes) was noted during each inspection visit. Those monitors with live termites present within wooden bundles during the time of inspection were reported as being "occupied." All field-collected, wood bundles containing termites were placed in a plastic bag and removed from the site. All termites contained within the wood bundle were removed and the number of termites visually estimated. This estimation was a modification of Haverty et al. (1974) and utilized five size classes to describe the number of termites observed in each monitoring station: 0 = 0; 1 = 1 to 100; 2 = 101 to 300; 3 = 301 to 1000; and 4 > 1000. To adjust for bias in visual estimates from field observers, the median value of each class (0, 0.5, 50, 150, 650.5, and 5000) was used as the estimated number of termites for each monitoring station. Hand counting of termites for some stations to check the accuracy of visual estimates exceeded 10,000, thus the 5000 median value for the highest size class. The monthly estimated number of termites for each monitoring station was the summation of the multiplied product of the station's termite size class (e.g., 0 to 4) and median value (0, 0.5, 50, 150, 650.5, or 5000). The data reported in this paper are the monthly percentage of monitoring stations occupied with subterranean termites and estimated total number of termites across all stations for each site. The period of monthly inspections of monitors was January 1994 to December 1996 for wildland site (IFG) and July 1994 to December 1996 for the residential site (Novato).

Results and Discussion

Few studies report the percentage of wooden stakes containing live subterranean termites or feeding damage. For south Florida, <7% of wooden stakes (groups of 100 or 200) were reported as infested with subterranean termites after several months in the ground (Su et al. 1993). In Australia, after 15 months in the ground, ≈21% (17 of 80) of wooden stakes were reported as attacked (e.g.,

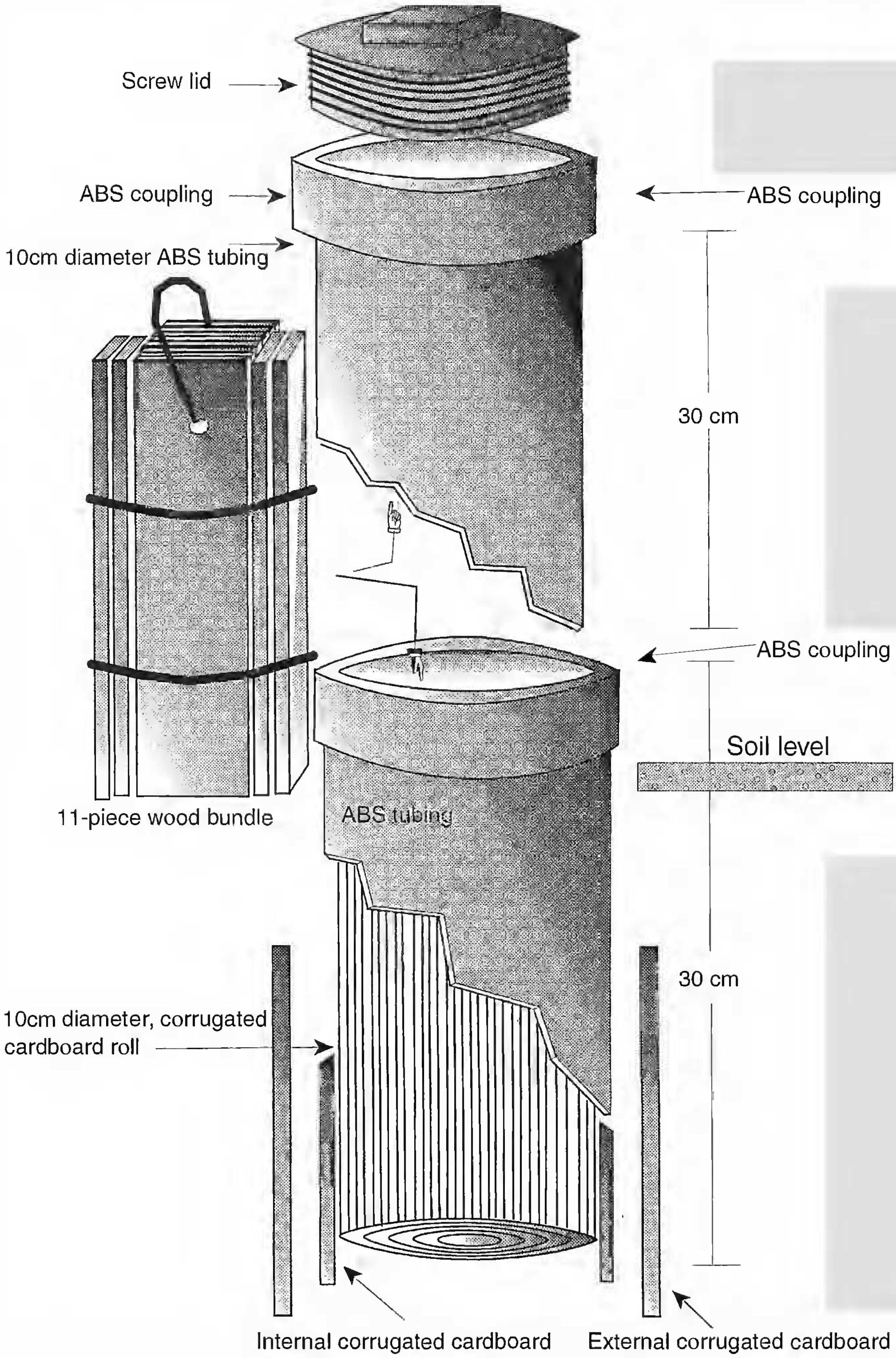

Figure 1. Cross-sectional schematic of ground-base monitor used for studying *Reticulitermes* foraging behavior in a wildland situation at the Institute of Forest Genetics, Placerville, California, and around and near structures at St. Francis Church, Novato, California.

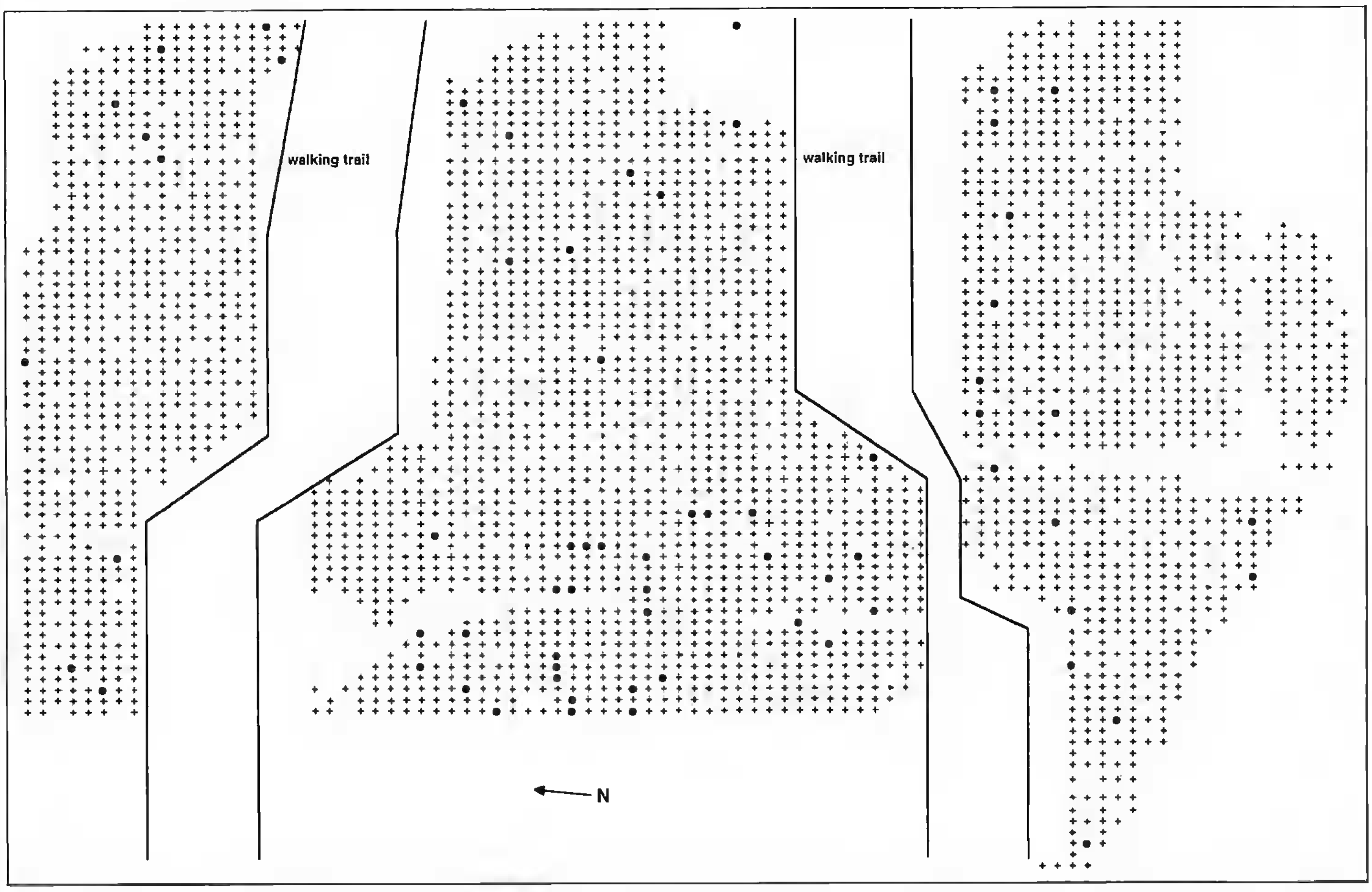

Figure 2. Distribution of monitoring station at the Institute of Forest Genetics, Placerville, California. Monitor locations designated as (●) in the figure, wooden stake locations designated as (+).

containing live termites, damage or both) by termites; 10% contained live termites (French & Robinson 1980).

For the current study, after six months (January 1993 to July 1993) in the ground at IFG, 6.7% of stakes (212 of 3138) contained termites or were damaged. Of the total number of damaged stakes, 2.9% (92 of 3138) contained live termites.

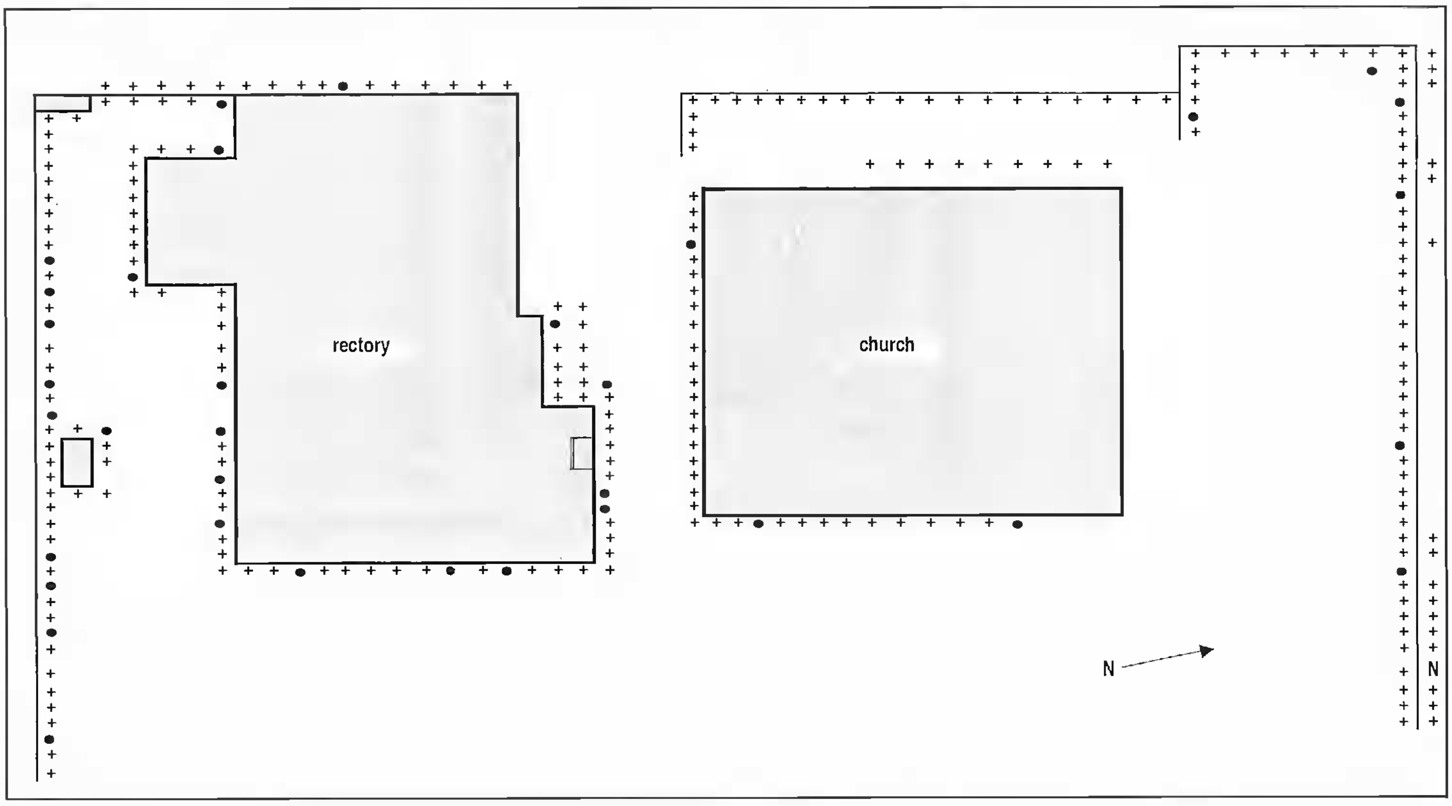

Figure 3. Distribution of monitoring stations at St. Francis Church, Novato, California. Monitor location designed as (●), wooden stake locations designated as (+).

After seventeen months (January 1993 to June 1994) in the ground at IFG, the percentage of wooden stakes containing live termites or damaged increased two-fold; 13.3% (417 of 3138). The percentage of stakes containing live termites after seventeen months increased slightly to 3.8% and remained at this level for an additional ten months (last stake inspection, April 1996). After four months in the ground at Novato, the percentage of wooden stakes containing live termites or damaged was 13% (29 of 223); double the rate of IFG and in a shorter time frame, less than four months. Shorter times for live termites first appearing on stakes have been reported, <2 months for south Florida (Thompson 1985). The percentage of stakes containing live termites for Novato was also slightly more than double that of IFG; 7.2% versus 2.9%, respectively. After about a year in the ground at Novato, the percentage of stakes containing live termites or feeding damage increased slightly, 17.1% (38 of 223). However, the percentage of stakes containing live termites at Novato after about one year almost doubled, 13.5% (30 of 223) and was more than three-fold greater than IFG even after three years. Lower percentages of stakes attacked by subterranean termites (*C. formosanus*) for southern California have been reported; 3% (Rust et al. 1998). Variances in reporting of stakes containing live termites and feeding damage are often attributed to habitat or geographical differences (Forschler & Townsend 1996).

Higher percentages of live termites and feeding damage 96% have been reported for the Desert subterranean termite *H. aureus* when using toilet paper rolls (LaFage et al. 1973). However, toilet paper can rapidly disintegrate under warm and humid field conditions (Su & Scheffrahn 1986) and much effort is needed to separate termites from the rolls and soil contaminants (La Fage et al. 1983). Similarly, because of quick consumption, disintegration, and difficulty in extracting termites, the use of corrugated paper alone is considered unsuitable for most subterranean termite foraging studies (Su & Scheffrahn 1986).

The first appearance of live termites and feeding damage in monitors after installation at our study sites was six months at IFG and five months at Novato. For IFG, within six months of installation, ≈20% of monitoring stations were occupied with subterranean termites (Fig. 4a). After six months of installation at Novato, the percentage of monitors occupied with live termites was 100% (Fig. 4b). The drop in percentage of stations occupied by live subterranean termites for both IFG and Novato sites during late summer and winter months was followed by a resurgence of occupation of at least 90% the following spring and suggest seasonality in forager number and activity (Fig. 4a, b). Summing across all stations, the total number of termites varied seasonally but at peak times approached 40,000 for Novato and 200,000 for IFG (Fig. 5). Similar findings in seasonality of forager number and activity for *Reticultermes* in undisturbed and urban sites (Haagsma & Rust 1995) and for *C. formosanus* (Haagsma et al. 1995) in a residential site have been reported for southern California. Haagsma and Rust (1995) have reported that foraging activity at an undisturbed site was related to minimum temperatures and for an urban site, minimum temperatures and precipitation.

The use of corrugated paper has been shown to hasten the construction of subterranean termite shelter tubes and incorporation of soil into the feeding substrate (Esenther 1980, La Fage et al. 1983). However, our results suggest that the use of corrugated paper below ground or none at all, did not influence the occurrence of live termites or feeding damage in stations at either wildland or res-

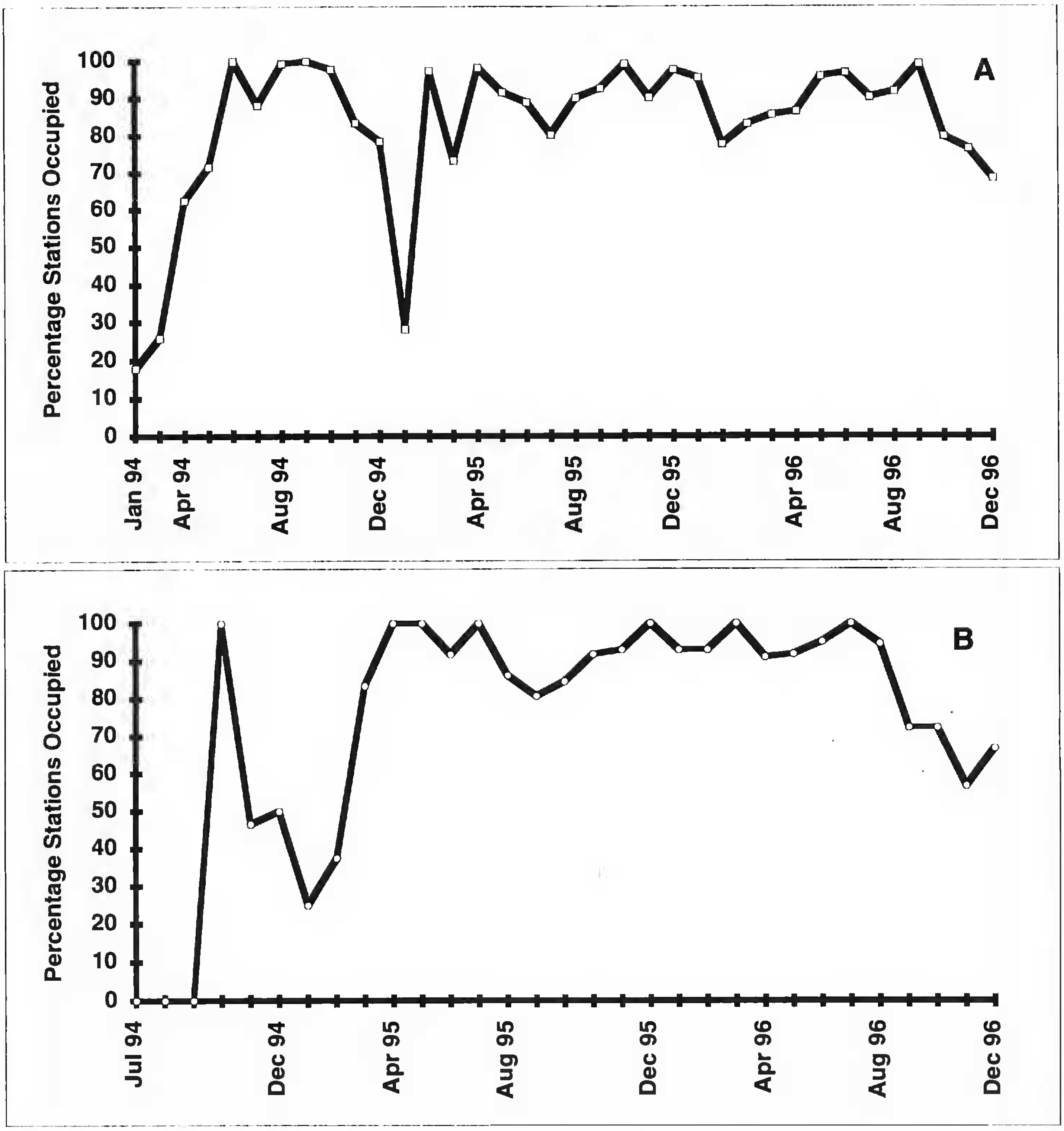

Figure 4. Percentage of monitoring stations occupied by *Reticulitermes* for A) Institute of Forest Genetics (IFG), Placerville, California, and B) St. Francis Church, Novato, California. Being occupied is defined as those monitors containing live termites and feeding damage during the time of inspection. Monitors installed in summer 1993 for IFG and spring 1994 and 1996 for the Novato site. Monthly inspections of monitors from January 1994 to December 1996 for IFG and July 1994 to December 1996 for the Novato site.

idential sites. The addition of the wooden bundles to the monitors insured sustained termite foraging long after the corrugated paper had disintegrated or was consumed.

After the monitoring stations were in place for eleven months, live subterranean termites and feeding damage for both sites exceeded 80% and remained at this high retention level through the remainder of the study; for IFG almost three years (Figs. 4a). This is the highest reported percentage of monitors with sustained live subterranean termites and feeding damage for wildland or residential habitats. Few comparable studies report the total number of monitors containing live ter-

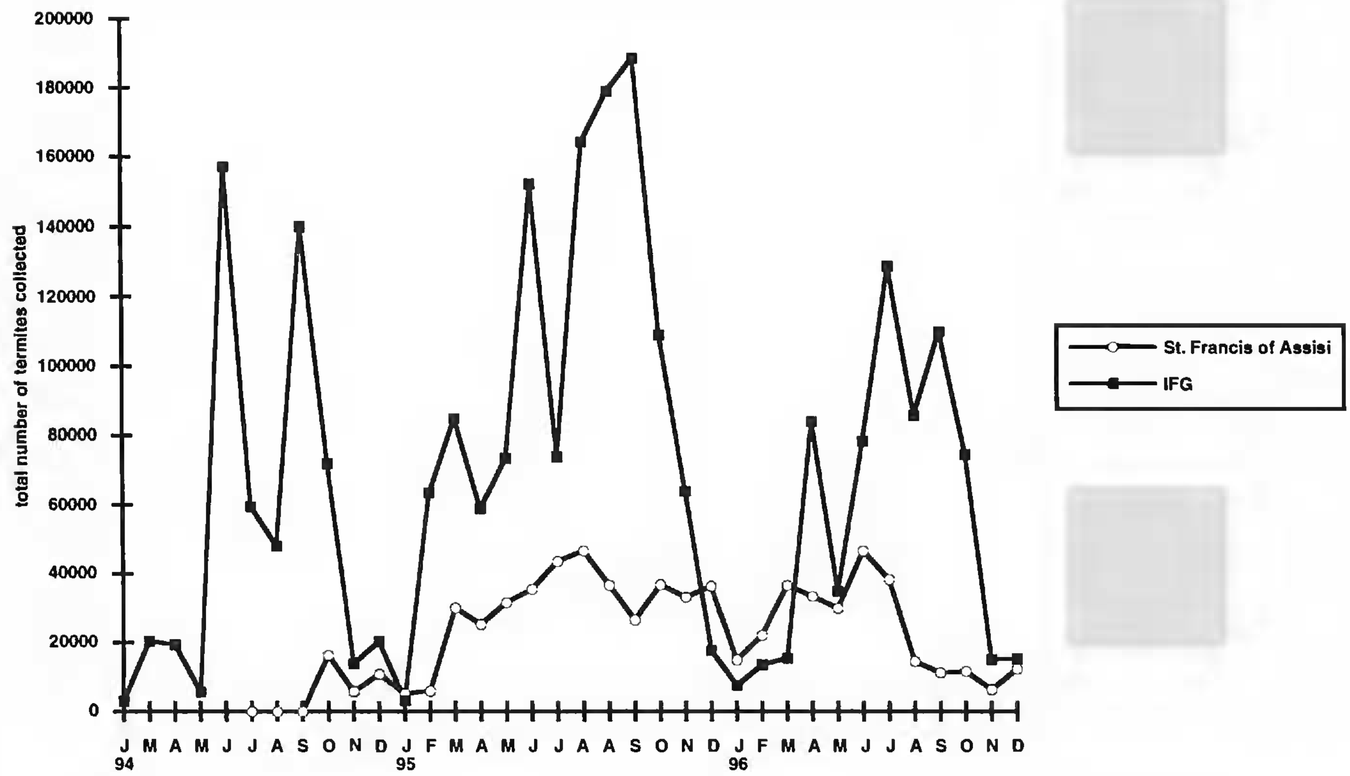

Figure 5. Monthly estimated total number of termites collected in monitoring stations at A) Institute of Forest Genetics (IFG), Placerville, California, and B) St. Francis Church, Novato, California. Total number of monitors for IFG and Novato were 65 and 39, respectively. Monitors installed in summer 1993 for IFG and spring 1994 and 1996 for the Novato site. Monthly inspections of monitors from January 1994 to December 1996 for IFG and July 1994 to December 1996 for the Novato site.

mites along with total number of monitors installed. Techniques used in monitor design and deployment also vary considerably among studies. Species differences in foraging behavior are also important (Haverty et al. 1976, French & Robinson 1980, Thompson 1985). However, it appears that the percentage of monitors containing live subterranean termites and feeding damage under field conditions is less than 50% (Grace et al. 1989, Haagsma & Rust 1995, Sornnuwat et al. 1996).

Reporting of termite numbers in monitors vary considerably. Most of these differences are attributed to habitat (Su et al. 1993), geographical location (Forschler & Townsend 1996), and climate (Haagsma & Rust 1995). Differences among species also undoubtedly affect foraging behavior (Haverty et al. 1976). For our study, the estimated total termite number (product of termite number size scale and median value) for individual monitors ranged from 0 to 5000; some of our hand counting estimates for individual monitoring stations exceeded 10,000 foragers (unpublished data). The number of termites collected from our monitor is comparable to reports from other large-volume traps which accommodate > 5000 foragers (Tamashiro et al. 1973, Su & Scheffrahn 1986, Grace 1989, Grace et al. 1989, Haagsma & Rust 1995, Forschler & Townsend 1996, Sornnuwat et al. 1996). Interestingly, all ground-base monitors harbor at least one or two orders of magnitude fewer termites compared to field-collected logs (Howard et al. 1982, Forschler & Townsend 1996).

Our current monitor design sustains a constantly high level of termite activity even though disruptions occur from monthly monitoring and termite removal operations. The ability to collect large numbers of termites could be incorporated into future field studies exploring caste proportions, colony biomass, wood consumption, and species determination using cuticular hydrocarbons. However, the monitor design and occupancy rates reported in this paper are probably more a function of seasonality of termite foraging and density at a particular field site. The initial prebaiting with wooden stakes before monitor installation also aided in the high percentage of monitors containing live termites and feeding damage. The principle advantage of our monitor design is sustaining relatively large numbers of termites foragers over time, rather than in "speeding up" the rate of discovery and attack of wooden bundles in monitors. More importantly, if the mechanisms behind the high levels of sustainability were better understood (e.g., high humidity levels in trap, possible heat attraction for termite foragers) these factors might be used in future commercial designs.

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Literature Cited

Beard, R. L. 1974. Termite biology and bait block method of control. Conn. Agric. Exp. Stn. Bull., 748.

Benson, E. P., J. K. Mauldin & E. S. Bordes. 1997. Evaluation of subterranean termite baiting strategies at urban sites with minimal soil access. Down to Earth, 52: 18–25.

Chen, J. & G. Henderson. 1994. Marking Formosan subterranean termites, *Coptotermes formosanus,* with rubidium (Isoptera: Rhinotermitidae). Sociobiology, 23: 17–26.

Ebeling, W. 1975. Urban Entomology. University of California Press, Berkeley, California.

Esenther, G. R. 1980. Estimating the size of subterranean termite colonies by a release-recapture technique. International Research Group on Wood Preservation Document IRG/WP/1112.

Esenther, G. R. & D. E. Grey. 1968. Subterranean termite studies in southern Ontario. Can. Entomol., 100: 827–834.

Esenther, G. R. & R. H. Beal. 1974. Attractant-mirex bait suppresses activity of *Reticulitermes* spp. J. Econ. Entomol., 67: 85–88.

Esenther, G. R. & R. H. Beal. 1978. Insecticidal baits on field plots perimeters suppress *Reticulitermes.* J. Econ. Entomol., 71: 604–607.

Ewart, D. McG., J. K. Grace, R. T. Yamamoto & M. Tamashiro. 1992. Hollow stakes for detecting subterranean termites (Isoptera: Rhinotermitidae). Sociobiology, 20: 17–22.

Forschler, B. T. 1994. Fluorescent spray paint as a topical marker on subterranean termites (Isoptera: Rhinotermitidae). Sociobiology, 24: 27–38.

Forschler, B. T. 1996. Baiting *Reticulitermes* (Isoptera: Rhinotermitidae) field colonies with abamectin and zinc borate-treated cellulose in Georgia. Sociobiology, 28: 459–484.

Forschler, B. T. & J. C. Ryder, Jr. 1996. Subterranean termite, *Reticulitermes* spp. (Isoptera: Rhinotermitidae), colony response to baiting with hexaflumuron using a prototype commercial termite baiting system. J. Entomol. Sci., 31: 143–151.

Forschler, B. T. & M. L. Townsend. 1996. Mark-release-recapture estimates of *Reticulitermes* spp. (Isoptera: Rhinotermitidae) colony foraging populations from Georgia, U.S.A. Environ. Entomol., 25: 952–962.

French, J. R. J. 1991a. Baits and foraging behavior of Australian species of *Coptotermes*. Sociobiology, 19: 171–186.

French, J. R. J. 1991b. Baiting techniques for control of *Coptotermes* species within existing buildings. pp. 46–50. *In* Haverty, M. I. & W. W. Wilcox (tech. coords.). Proc. of the Symposium on Current Research on Wood-Destroying Organisms and Future Prospects for Protecting Wood in Use. USDA Forest Service Gen. Tech. Rep. PSW-128.

French, J. R. J. & P. J. Robinson. 1980. Field baiting of some Australian subterranean termites. Z. Angew., Entomol., 90: 444–449.

French, J. R. J. & P. J. Robinson. 1981. Baits for aggregating large numbers of subterranean termites. J. Aust. Entomol. Soc., 20: 75–76.

French, J. R. J. & P. J. Robinson. 1985. A technique used on mounds of *Coptotermes lacteus* to screen potential bait substrates. J. Aust. Ent. Soc., 24: 111–112.

Fujii, J. K. 1975. Effects of an entomogenous nematode, *Neoplectana carpocapsae* Weiser, on the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, with ecological and biological studies on *C. formosanus*. Ph.D. Dissertation University of Hawaii, Honolulu, Hawaii.

Grace, J. K. 1989. A modified trap technique for monitoring *Reticulitermes* subterranean termite populations (Isoptera: Rhinotermitidae). Pan-Pac. Entomol., 65: 381–384.

Grace, J. K. 1990. Mark-recapture studies with *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). Sociobiology, 16: 297–303.

Grace, J. K. 1992. Termite distribution, colony size, and potential for damage. pp. 67–76. *In* Robinson, W. H. (ed.). Proc. National Conference on Urban Entomology, 23–26 Feb. 1992, College Park, Maryland.

Grace, J. K. & A. Abdallay. 1989. Evaluation of the dye marker Sudan Red 7B with *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). Sociobiology, 15: 71–77.

Grace, J. K. & A. Abdallay. 1990. A short-term dye for marking eastern subterranean termites (*Reticulitermes flavipes* Koll.) (Isoptera, Rhinotermitidae). J. Appl. Ent., 109: 71–75.

Grace, J. K., A. Abdallay & K. R. Farr. 1989. Eastern subterranean termite (Isoptera: Rhinotermitidae) foraging territories and populations in Toronto. Can. Entomol., 121: 551–556.

Grace, J. K., J. R. Yates III & C. H. M. Tome. 1995. Modification of a commercial bait station to collect large numbers of subterranean termites (Isoptera: Rhinotermitidae). Sociobiology, 26: 259–268.

Grace, J. K., C. H. M. Tome, T. G. Shelton, R. J. Oshiro & J. R. Yates III. 1996. Baiting studies and considerations with *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in Hawaii. Sociobiology, 28: 511–520.

Haagsma, K. A. & M. K. Rust. 1995. Colony size estimates, foraging trends, and physiological characteristics of the western subterranean termite (Isoptera: Rhinotermitidae). Environ. Entomol., 24: 1520–1528.

Haagsma, K., M. K. Rust, D. A. Reierson, T. H. Atkinson & D. Kellum. 1995. Formosan subterranean termite established in California. California Agriculture, 49: 30–33.

Haverty, M. I. & W. L. Nutting. 1975. Density, dispersion, and composition of desert termite foraging populations and their relationship to superficial dead wood. Environ. Entomol., 4: 480–486.

Haverty, M. I. & L. J. Nelson. 1997. Cuticular hydrocarbons of *Reticulitermes* from California: indications of additional species. Comp. Biochem. Physiol., 118B: 869–880.

Haverty, M. I., J. P. LaFage & W. L. Nutting. 1974. Seasonal activity and environmental control of foraging of the subterranean termite, *Heterotermes aureus* (Snyder), in a desert grassland. Life Science, 15: 1091–1101.

Haverty, M. I., W. L. Nutting & J. P. La Fage. 1975. Density of colonies and spatial distribution of foraging territories of the desert subterranean termite, *Heterotermes aureus* (Snyder). Environ. Entomol., 4: 105–109.

Haverty, M. I., W. L. Nutting & J. P. La Fage. 1976. A comparison of two techniques for determining abundance of subterranean termites in an Arizona desert grassland. Insectes Soc., 23: 175–178.

Hedges, S. 1992. Termite inspections. Pest Control Tech., 20: 30–33.

Howard, R. W., S. C. Jones, J. K. Mauldin & R. H. Beal. 1982. Abundance, distribution, and colony size estimates for *Reticulitermes* spp. (Isoptera: Rhinotermitidae) in southern Mississippi. Environ. Entomol., 11: 1290–1293.

Jones, S. C. 1990. Delineation of *Heterotermes aureus* (Isoptera: Rhinotermitidae) foraging territories in a Sonoran desert grassland. Environ. Entomol., 19: 1047–1054.

Jones, S. C., M. W. Trosset & W. L. Nutting. 1987. Biotic and abiotic influences on foraging of *Heterotermes aureus* (Snyder) (Isoptera: Rhinotermitidae). Environ. Entomol., 16: 791–795.

La Fage, J. P., W. L. Nutting & M. I. Haverty. 1973. Desert subterranean termites: A method for studying foraging behavior. Environ. Entomol., 2: 954–956.

La Fage, J. P., N.-Y. Su, M. J. Jones & G. R. Esenther. 1983. A rapid method for collecting large numbers of subterranean termites from wood. Sociobiology, 7: 305–309.

Lai, P. Y. 1977. Biology and ecology of the Formosan subterranean termite, *Coptotermes formosanus,* and its susceptibility to the entomogenous fungi, *Beauveria bassiana* and *Metarrhizium anisopliae.* Ph.D. Dissertation University of Hawaii, Honolulu, Hawaii.

Lai, P. Y., M. Tamashiro, J. K. Fujii, J. R. Yates & N.-Y. Su. 1983. Sudan Red 7B, a dye marker for *Coptotermes formosanus.* Proc. Hawaii. Entomol. Soc., 24: 277–282.

Lenz, M. & J. W. Creffield. 1993. A below-ground exposure method for determining the resistance of woody and non-woody materials to attack by subterranean termites. International Research Group on Wood Preservation Document IRG/WP/93-10012.

Oi, F. M. & N.-Y. Su. 1994. Stains tested for marking *Reticulitermes flavipes* and *R. virginicus* (Isoptera: Rhinotermitidae). Sociobiology, 24: 241–268.

Pawson, B. M. & R. E. Gold. 1996. Evaluation of baits for termites (Isoptera: Rhinotermitidae) in Texas. Sociobiology, 28: 485–510.

Potter, M. F. 1997. Termite baits: status report. Pest Control Tech., 25: 24–26,28,30,35–37,97,105–106,110.

Rust, M. K., D. A. Reierson, E. O. Paine, D. Kellum & K. Haagsma. 1998. Ravenous Formosan subterranean termites persist in California. California Agriculture, 52: 34–37.

Sornnuwat, Y., K. Tsunoda, T. Yoshimura, M. Takahashi & C. Vongkaluang. 1996. Foraging populations of *Coptotermes gestroi* (Isoptera: Rhinotermitidae) in an urban area. J. Econ. Entomol., 89: 1485–1490.

Spragg, W. T. & R. Paton. 1980. Tracing, trophallaxis and population measurement of colonies of subterranean termites (Isoptera) using a radioactive tracer. Ann. Entomol. Soc. Am., 73: 708–714.

Su, N.-Y. 1994. Field evaluation of a hexaflumuron bait for population suppression of subterranean termites (Isoptera: Rhinotermitidae). J. Econ. Entomol., 87: 389–397.

Su, N.-Y. & R. H. Scheffrahn. 1986. A method to access, trap, and monitor field populations of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in the urban environment. Sociobiology, 12: 299–304.

Su, N.-Y. & R. H. Scheffrahn. 1988. Foraging population and territory of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in an urban environment. Sociobiology, 14: 353–359.

Su, N.-Y. & R. H. Scheffrahn. 1990. Economically important termites in the United States and their control. Sociobiology, 17: 77–94.

Su, N.-Y., M. Tamashiro, J. Yates, P.-Y. Lai & M. I. Haverty. 1983. A dye, Sudan Red 7B, as a marking material for foraging studies with the Formosan subterranean termite. Sociobiology, 8: 91–97.

Su, N.-Y., P. M. Ban & R. H. Scheffrahn. 1991. Evaluation of dye markers for populations studies of the eastern and Formosan subterranean termites (Isoptera: Rhinotermitidae). Sociobiology, 19: 349–362.

Su, N.-Y., P. M. Ban & R. H. Scheffrahn. 1993. Foraging populations and territories of the eastern subterranean termite (Isoptera: Rhinotermitidae) in southeastern Florida. Environ. Entomol., 22: 1113–1117.

Su, N.-Y., E. M. Thoms, P. M. Ban & R. H. Schreffrahn. 1995a. Monitoring/baiting station to detect and eliminate foraging populations of subterranean termites (Isoptera: Rhinotermitidae) near structures. J. Econ. Entomol., 88: 932–936.

Su, N.-Y., R. H. Scheffrahn & P. M. Ban. 1995b. Effects of sulfluramid-treated bait blocks on field colonies of the Formosan subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol., 88: 1343–1348.

Tamashiro, M., J. K. Fujii & P. Y. Lai. 1973. A simple method to observe, trap and prepare large numbers of subterranean termites for laboratory and field experiments. Environ. Entomol., 2: 721–722.

Thompson, C. R. 1985. Bait stake detection of the Formosan termite in south Florida. Fla. Entomol., 68: 641–645.

Thorne, B. L., E. Russek-Cohen, B. T. Forschler, N. L. Breisch & J. F. A. Traniello. 1996. Evaluation of mark-release-recapture methods for estimating forager population size of subterranean termite (Isoptera: Rhinotermitidae) colonies. Environ. Entomol., 25: 938–951.

Uekert, D. N., M. C. Bodine & B. M. Spears. 1976. Population density and biomass of the desert termite *Gnathamitermes tubiformans* (Isoptera: Termitidae) in a short-grass prairie: Relationship to temperature and moisture. Ecology, 57: 1273–1280.

Weesner, F. M. 1965. The Termites of the United States: a Handbook. The National Pest Control Association, Elizabeth, New Jersey.

Weesner, F. M. 1970. Termites of the Neartic Region. Pp. 477–525. F. M. Weesner & Krishna (eds.). *In* Biology of Termites, Vol. I Academic Press, New York and London.

Wilson, E. O. 1971. The Insect Societies. Belknap Press, Cambridge, Massachussetts.

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